# *A study of the effects of substrate type on the benthic macroinvertebrate fauna in the river Wear, county Durham*

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# A STUDY OF THE EFFECTS OF SUBSTRATE TYPE ON THE BENTHIC MACROINVERTEBRATE FAUNA IN THE RIVER WEAR, COUNTY DURHAM

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## Preface

This dissertation is submitted as part of the requirements for the degree of Master of Science in Ecology at the University of Durham, 1986.

## Acknowledgements

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CONTENTS

## 1. SUMMARY


1. A study was made of the fauna of two adjacent riffles in the River Wear, with substrates of different type, one cobble (stones less than 15cm diameter) and the other boulder (stones greater than 15cm diameter).

2. The results show species diversity to have been greatest in the boulder substrate. This is thought to be due to higher substrate heterogeneity with a greater number of physical and ecological niches in the boulder substrate.

3. Molluscs were generally more diverse and common in the boulder substrate. Hydrobia jenkinsi was particularly common. Ancylus fluviatilis, however, became increasingly abundant on the cobble substrate.

4. Tricladia were found only in the boulder substrate but Hirudinea, conversely, had higher overall abundance and diversity in the cobble substrate.

5. Crustacea were more abundant in the boulder substrate and Gammarus pulex reached particularly high numbers.

6. Some species of Ephemeroptera were more abundant in the cobble substrate (Caenis macrura, Ecdyonurus dispar and Rithrogenia semicolorata) and some in the boulder substrate (Baetis rhodani and Ephemerella ignita).

7. There were found to be significant differences in composition of size classes between substrata in *Baetis rhodani*. The population on the cobble substrate also appeared to be more synchronous.

8. The two populations of *Ephemerella ignita* also showed significant differences and this was probably in part attributable to the adult female of the species which lays eggs at the water surface. These are caught up in moss which was present only on the boulder substrate.

9. Trichoptera were generally more common in the boulder substrate. This was particularly noticeable in the Hydropsychidae - the most common family.

10. There was a significant difference between population of *Hydropsyche siltalai* on the two substrates. This species requires a crevice in the substrate from which it constructs its feeding net. These niches were more common in the boulder substrate.

11. Coleoptera adults and larvae were found in both riffles although infrequently. A number of species of Diptera were also identified. These are listed in Appendix 2.

## 2. INTRODUCTION

The substrate, or bottom, of a river or stream varies in nature according to the local geology, but more importantly according to the velocity of the water flow. There is therefore an important ecological gradient of substrate particle size. At one end of this gradient there is fine silt, where the current velocity is least, then sands, gravels and stones of increasing coarseness as the velocity increases. Stony substrates can be sub-divided into cobble (stones less than 15cm diameter) and boulder (stones greater than 15cm diameter). Over the former, the water surface is riffled whereas over the latter it is highly riffled or even cascades. The finest substrates are usually seen in lowland reaches of rivers, with more coarse substrates in upland zones where the flow is often torrential. In addition to this gradient from head waters to estuary, there can also be changes over much shorter distances of water. In the middle reaches of a river there are often sections comprising riffles and pools where the nature of the substrate varies considerably over a few metres or even less.

The present study was concerned with comparing the invertebrate fauna of two riffles, the substrate of which lay at the upper end of the substrate particle size gradient. They were namely a cobble riffle with stones less than 15cm diameter, and a boulder cascade with stones greater than 15cm diameter.

The relative importance of current velocity and substrate to macroinvertebrates has been debated in many articles (e.g. Hera, 1936; Linduska, 1942) with different conclusions reached. The contention revolves around two points: (1) That current velocity has an undoubted effect on substrate formation (with geological limitations) either by erosion or deposition, (2) Few species are directly exposed to the full force of the current as they live within, or close to, the surface of the substrate and the substrate nature is therefore most directly important.

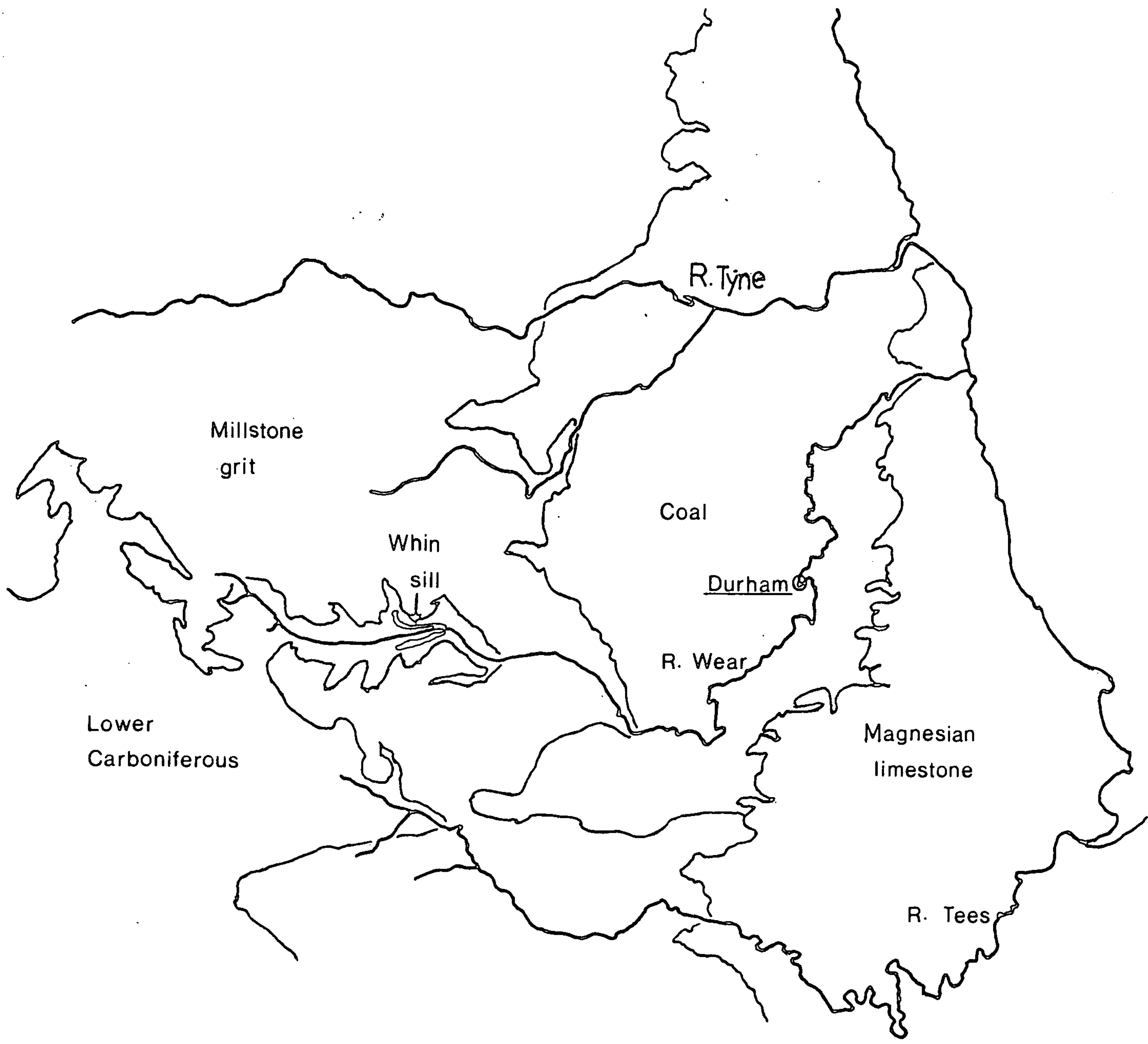
It seems clear that the relative importance of substrate and current will vary, to some extent, with the biology of individual species. The species which live on the upper surfaces of stones, for example, will be better adapted to withstand high current velocities than those which live deeper within the substrate, and current velocity may play a more important part in influencing their biology.

Although the importance of these two factors must be stressed, practical considerations linked with the short period of time available for field study meant that attempts to measure the current velocities at each riffle were abandoned in favour of a qualitative approach to this factor. It was felt that as current velocity can vary considerably in a short space of time, there would be effects on the fauna which could not be accounted for accurately. There is also a complex micro-pattern of varying water velocities in a few centimetres distance, or less, within a stony riffle - a pattern which would be difficult to record or represent. Misleading information may have led to erroneous conclusions. It was therefore decided to focus largely on the substrate.

Hynes (1970) states that the larger the stones and hence the more complex the substratum, the more diverse is the invertebrate fauna. By this he meant that in and around large stones there will be more sites available for colonisation by invertebrates, and that the more heterogenerous the substrate, the more niches there will be for a different species. Conversely, sites with small stones or still finer substrates provide fewer niches because they are more uniform in nature. It is interesting to note that in boulder riffles where the water velocity is high, there are microhabitats of low current flow within the substrate. In these spaces, pockets of detritus may accumulate, consisting largely of higher plant remains. These provide a patchy food resource for invertebrates. Hynes' view has long been accepted, and many articles offer proof for his theory, for example Sprules (1947) and Tarzwell (1936).

Other studies (e.g. Williams, 1980) fail to find any significant relationship between substrate particle size and invertebrate abundance or diversity. There is therefore, a degree of controversy surrounding this issue.

Most of the studies which have been made consider large differences in substrate type, such as between the substrates of pools and riffles ( Scullion et al, 1982). or a large range of substrates from sand and gravel to cobble (e.g. Linduska, 1942). Few studies have considered smaller variations, particularly at the upper end of the substrate particle size continuum. In this study, the aims were to discover, and to quantify where possible, differences in the fauna of two adjacent riffles, where the substrates were cobble and boulder respectively. The proximity of the two study areas meant that other environmental parameters such as water temperature and chemistry could be considered to be closely similar.




Map 1 The three major river systems in North Eastern England in relation to geological features.

## 3. DESCRIPTION OF THE RIVER AND STUDY SITE

### (a) The River Wear

The river rises in Lower Carboniferous rocks in the west of County Durham and runs its entire course within the county. The headwaters are in Pennine moorland close to the sources of both Tyne and Tees. The river crosses the Durham coalfield and passes briefly over magnesian limestone before entering the North Sea (see MAP 1).

There has been a close association with industry - lead and coal waste formerly drained into the Wear causing gross inorganic pollution with a severe reduction in fish stocks. The lower reaches of the river also became polluted with domestic sewage as the populations of Durham city and other centres increased. The reduction in coal and lead extraction together with improved sewage treatment have led to the Wear becoming largely free of gross pollution today.

It is interesting to compare the invertebrate fauna of the Wear in the Durham city area today with that of 1966/67 when the river was still highly polluted. In many respects the fauna is similar, although there are noteworthy differences, particularly in the Plecoptera and Gastropoda (L.Davies pers. comm.). The increased health of the river has led Northumbrian Water Authority to try to re-establish salmon, once common in the Wear. It is too early to tell whether or not this has been successful.

### (b) The sampling stations

The study area was ¾km downstream of Durham city centre in an area known as The Sands. This stretch of the Wear consists of riffles and pools typical of the mid-reaches of a river and is approximately 25-40m wide. It is patronised by local anglers. Station 1 has open access but at station 2 fishing rights are held by the Dunelm Anglers Association. The two sampling stations were in close proximity - about 400m apart - minimising differences in water quality (see Map 2).

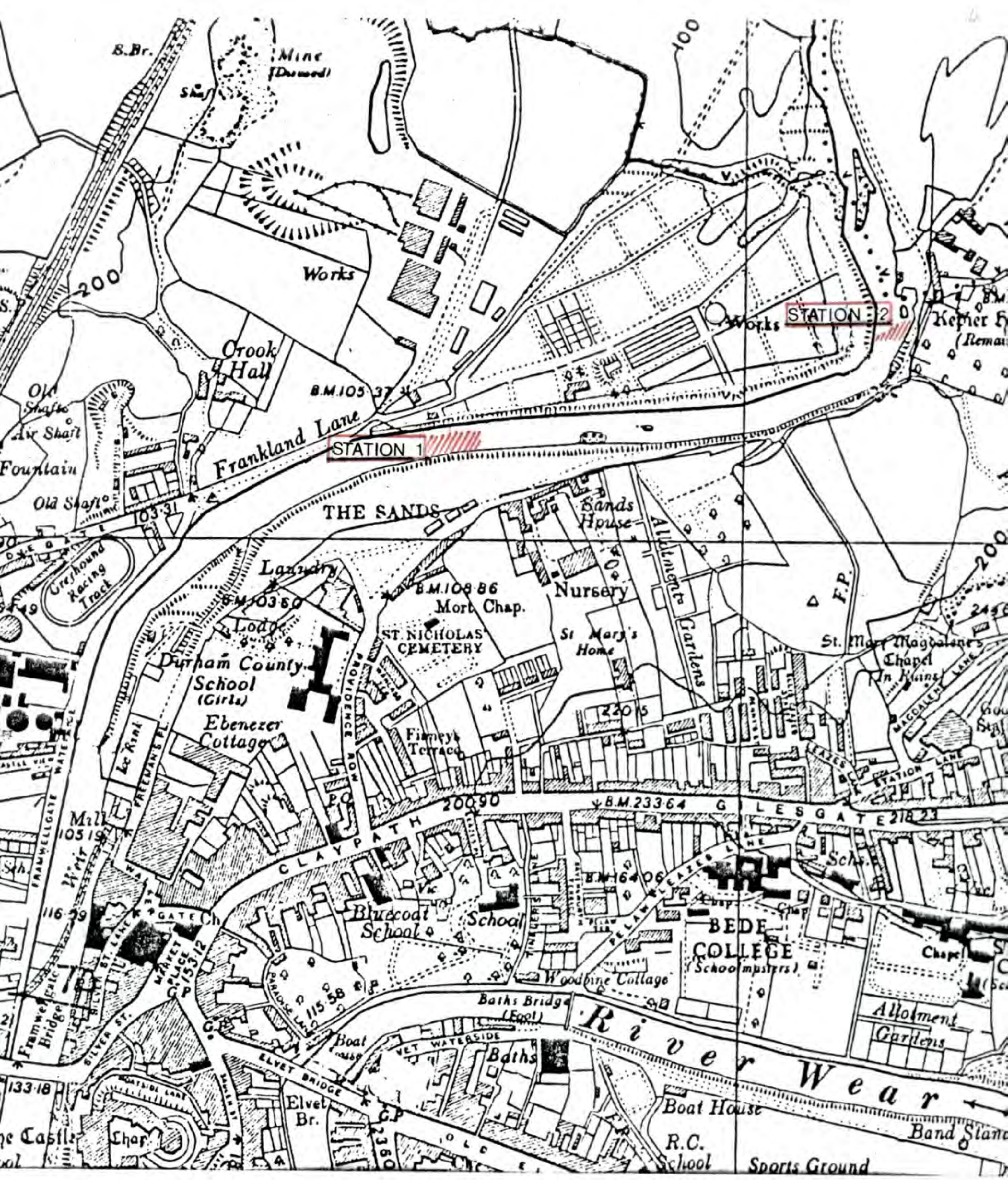
Station 1

This was an extensive riffle over nearly two thirds of the width of the river, which was approximately 40m wide. The remaining one third formed a deeper channel. The water was shallow, generally less than 30cm deep during the study period, although there was evidence of greater depth between sampling dates. The substrate consisted of stones 10-15cm diameter - cobble - embedded in gravel and finer deposits. As a result of this siltation there were virtually no large gaps between stones. Instead there were narrow slits and small spaces. Invertebrates therefore had to attach themselves to the upper surfaces of stones or to burrow beneath them. The stones were largely worn to a regular shape so that they fitted together, and this combined with the silt between stones helped to increase stability in the substrate so that stones remained in position except during the highest spates. The filamentous alga Cladophora rupestris became increasingly abundant and luxuriant during the study period, particularly from early June.

Station 2

This riffle, although of lesser area extended over the whole width of the river - approximately 30m - and was wedge shaped. The riffle represented the remains of a man-made stone-built weir of which the larger stones remain. The water was generally deeper, although rarely above 50cm and the current speed was greater. The substrate consisted of large, irregularly-shaped stones, often more than 30cm diameter, known as boulders. These stones rested on larger rocks and there was very little fine material deposited. There were large gaps between stones and niches in the surfaces of the stones themselves. The gaps between boulders formed traps for leaves and other fragments of higher plants unlike the substrate at station 1. The boulders remained in position during spates, largely due to their size and weight, but any debris was liable to be washed away. Cladophora was present as at station 1 and in addition the moss Fontinalis sp. was present throughout the study period on 15-20% of the stones.

The different appearances of the two stations are shown in plates 1A and 2A and the nature of the two substrates is shown in plates 1B and 2B. The dimension of the tray in the latter two plates was 50cm x 40cm.




<u>Map 2</u> The location of sampling stations 1 and 2 on the River Wear, County Durham.

Plate 1

A Stationl.

B Substrate at station 1

Plate 2

A Station 2.

B Substrate at station 2.

## 4. MATERIALS AND METHODS

Fieldwork was initially intended to be carried out involving at least monthly sampling interspersed with laboratory studies. Unfortunately the species considered most suitable for further investigation were not sufficiently abundant and it was decided to base the project entirely on fieldwork. As a result of this, two sampling methods were used.

### Method 1

This method was intended to complement laboratory studies and was used only on the first and final sampling dates - April 28 and July 17. A 33x33cm quadrat ($^1/_9$ $m^2$) was placed on the substrate and a 0.25mm mesh dredge net held to the substrate immediately downstream of the quadrat. The bottom was then vigorously stirred by hand for two minutes so that animals and detritus were washed into the net and could be transferred to suitable containers for transport back to the laboratory. Sources of error inherent in this method, as in many stream sampling methods, include loss of animals from within the quadrat area over under or around the edges of the net.

### Method 2

This method was devised to give results comparable to method 1. without entailing the same length of time for sorting. This method was used on May 29, June 3 and 19, July 1,10 and 17. The quadrat was placed on the substrate with the net in position at the downstream edge as in method 1. The surface layer of stones was then quickly lifted into a bucket. Any drifting organisms were caught in the net. These samples were largely sorted at the riverside by removing all invertebrates from the stones and net into containers for transfer to the laboratory. Large predators and fragile species were kept separate, as appropriate.

Five or six replicate samples were usually taken at each sampling station on each date and for both methods. The condition and state of growth of aquatic macrophytes was noted.

Prior to sorting, all samples were held at 1°C to keep the animals alive for as long as possible. All Insecta, except Diptera, and all Mollusca, Tricladia, Hirudinea and Crustacea were identified to species where appropriate keys were available, and counted. The most abundant species were divided into three size classes - small, medium and large - decided by eye. The size limits of these classes are given in the results. Diptera, Oligochaetae and mites were not included because they were often too abundant to allow accurate identification within the scope of this project, and many species were fragile and reached the laboratory in poor condition. Also, method 2 probably did not give an accurate estimate of the numbers of these small invertebrates as many would have been missed during the first sorting. Some species were identified, however, where keys were available and added to the general species list (appendix 2).

Sampling was obviously affected by the weather, it being difficult to obtain samples when the river is in spate. As the spring and summer of 1985 were cold and wet, the river was high on a larger percentage of visits than would have been expected and sampling could only take place irregularly. Indeed, the total sampling carried out was less than had been planned because the river was in flood on too many days during the period of this study (late April - late July 1985).

## 5. RESULTS

For most species of invertebrate there was insufficient data gathered for full statistical treatment, allowing only a qualitative assessment of the effects of substrate variation. For a few species, however, a larger volume of data was acquired and this has been subjected to a more rigorous treatment, particularly the division of samples into size classes allowing assessment of relative growth and performance in each substrate. The results have therefore been divided into two sections covering both aspects of the data.

### A. Comparative and mainly qualitative results

MOLLUSCA

Gastropods were abundant at both sampling stations, particularly towards the end of the sampling period when a rapid increase in the numbers of *Ancylus fluviatilis* and *Hydrobia jenkinsi* was seen (Table 1). *Lymnaea peregra* also became more common at this time. Freshwater Gastropods feed by rasping algal layers from the surfaces of rocks and macrophytes, rarely feeding on multicellular algae and vascular plants. A hard surface is required for attachment and movement and more species can therefore be found in slowly flowing water than in standing water as there is less silt deposition.

*Ancylus* is a small limpet-like mollusc often associated with swiftly flowing water. The species is known to have an aversion to mud (Boycott, 1936). It was present throughout the study period and became increasingly abundant towards the latter end, particularly on the cobble substrate, and to a lesser extent, on the boulder - see Fig. 1. *Hydrobia* on the contrary, first appeared in samples from mid-June and and achieved a very rapid rate of increase on the boulder substrate whilst the population at station 1 remained fairly static- see Fig. 2. This species was first recorded in freshwater in 1893 and has since colonised most types of running water. *Hydrobia* is parthenogenetic and

Table 1 Numbers per metre square of main species of invertebrates in the River Wear at Durham, May to July 1985. For raw data see Apendix 1.

| | May 29 | | June 3 | | June 19 | | July 1 | | July 10 | | July 19 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | stn1 | stn2 | stn1 | stn2 | stn1 | stn2 | stn1 | stn2 | stn1 | stn2 | stn1 | stn2 |
| | C | B | C | B | C | B | C | B | C | B | C | B |
| MOLLUSCA | | | | | | | | | | | | |
| A. fluviatilis | 25 | 11 | 17 | 39 | 9 | 32 | 10 | 29 | 164 | 60 | 140 | 74 |
| H. jenkinsi | | | | | 2 | 32 | 2 | 109 | 5 | 852 | 7 | 554 |
| L. peregra | | | | | | | | | | 15 | | 7 |
| Pisidium sp. | 2 | 3 | | 5 | | 3 | | 4 | | 12 | | 12 |
| TRICLADIA | | | | | | | | | | | | |
| D. ligubris | | 3 | | 3 | | 30 | | 4 | | 6 | | 11 |
| P. tenuis | | 3 | | 5 | | 21 | | 2 | | 2 | | 36 |
| HIRUDINEA | | | | | | | | | | | | |
| E. octoculata | 36 | | 18 | 6 | 24 | 21 | 11 | 11 | 5 | 9 | 23 | 2 |
| G. complanata | 3 | | | | 2 | 2 | | | | | 4 | 2 |
| H. stagnalis | | | 2 | | 5 | | | | | | 2 | |
| CRUSTACEA | | | | | | | | | | | | |
| A. aquaticus | 6 | 11 | 3 | | | 9 | 7 | 22 | 5 | 20 | 14 | 38 |
| G. pulex | 9 | 171 | 38 | 213 | 3 | 368 | 13 | 410 | 14 | 393 | 11 | 167 |
| INSECTA | | | | | | | | | | | | |
| Plecoptera | | | | | | | | | | | | |
| I. grammatica | | | | 3 | | | 2 | | | | 2 | |
| Ephemeroptera | | | | | | | | | | | | |
| B. rhodani | 6 | 12 | 20 | 14 | 57 | 23 | 142 | 236 | 374 | 462 | 99 | 275 |
| C. macrura | | | | | 84 | 9 | 49 | 5 | 36 | 11 | 31 | |
| E. dispar | | | | | | | 18 | 9 | 57 | 23 | 67 | 27 |
| E. ignita | | | | | 181 | 398 | 576 | 1120 | 870 | 1038 | 659 | 558 |
| R. semicolorata | | | 2 | | 5 | 2 | 2 | | | | | |
| Trichoptera | | | | | | | | | | | | |
| A. multipunctata | | | | | | | 18 | 4 | 24 | 27 | 7 | 18 |
| A. bilineatus | | | | | 3 | 6 | 5 | 9 | 2 | 5 | | |
| H. angustipennis (l) | 2 | 5 | | | | | | | 15 | 69 | 29 | 176 |
| H. siltalai (l) | 128 | 318 | 117 | 569 | 53 | 230 | 23 | 72 | 17 | 11 | 2 | 2 |
| Leptoceridae sp. | 120 | 56 | 122 | 197 | 74 | 108 | 194 | 164 | 8 | 8 | | |
| P. flavomaculatus | | | | | | | | | | | 4 | |
| R. dorsalis | | 2 | 2 | | 2 | 2 | 2 | | | 5 | | 14 |
| Coleoptera | | | | | | | | | | | | |
| E. aenea (l) | | | | | | | | | 2 | | 2 | 4 |
| E. parallelepipedus | | | | | | | 2 | | 2 | | | |
| H. elegans | 2 | 2 | 3 | | | | | | | 2 | | |
| L. volckmari (l) | | | 2 | 8 | | | 2 | 2 | 2 | | 2 | |
| L. volckmari (a) | | | 2 | | | | 2 | | | 2 | | |

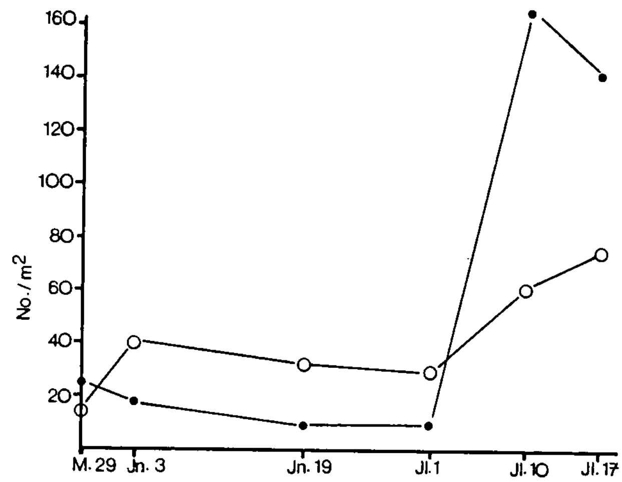
C - cobble substrate
B - boulder substrate
(l) - larvae
(a) - adult

viviparous allowing rapid rates of reproduction in favourable conditions.

There is a clear difference between these two species in the substrate on which they are most successful. Hydrobia may have fared worse on the cobble substrate because the small interstices would not support a high growth of epilithic algae such that molluscs would have to seek food on the upper surfaces of stones. Ancylus with its streamlined and flattened shell would be better adapted to withstand water flow than would Hydrobia which has a taller shell. The young stages of Hydrobia would be particularly vulnerable to being swept downstream as they are unable to form as strong an attachment as mature individuals. In the boulder substrate on the other hand, the larger interstices allow organisms to escape from the full force of the current, and as light can penetrate between these large stones, an algal film will be present. Thus young Hydrobia will have a higher survival rate. Why Ancylus should be less successful (i.e. less abundant) on the boulder substrate is not clear.

Lymnaea was not found at station 1 and was only collected from the edges of the boulder riffle where the current was least strong. This relatively large species would also benefit from large interstices as it could not feed when burrowed beneath cobble-type stones. Pisidium sp. was also found mainly in the boulder substrate. This genus requires mud or silt, but whether this is for burrowing into or for food Boycott (1936) is unclear. It would seem from these results that the species is able to survive where there is very little deposition for burrowing into and Pisidium probably requires organic deposits for filter-feeding. Pisidium, like Hydrobia, is viviparous and it appears that this is a useful adaptation for life in running waters by cutting out the vulnerable egg stage.

Figure 1 Comparison of numbers per $m^2$ of *Ancylus fluviatilis* in cobble and boulder substrates through the sampling period May to July 1985.



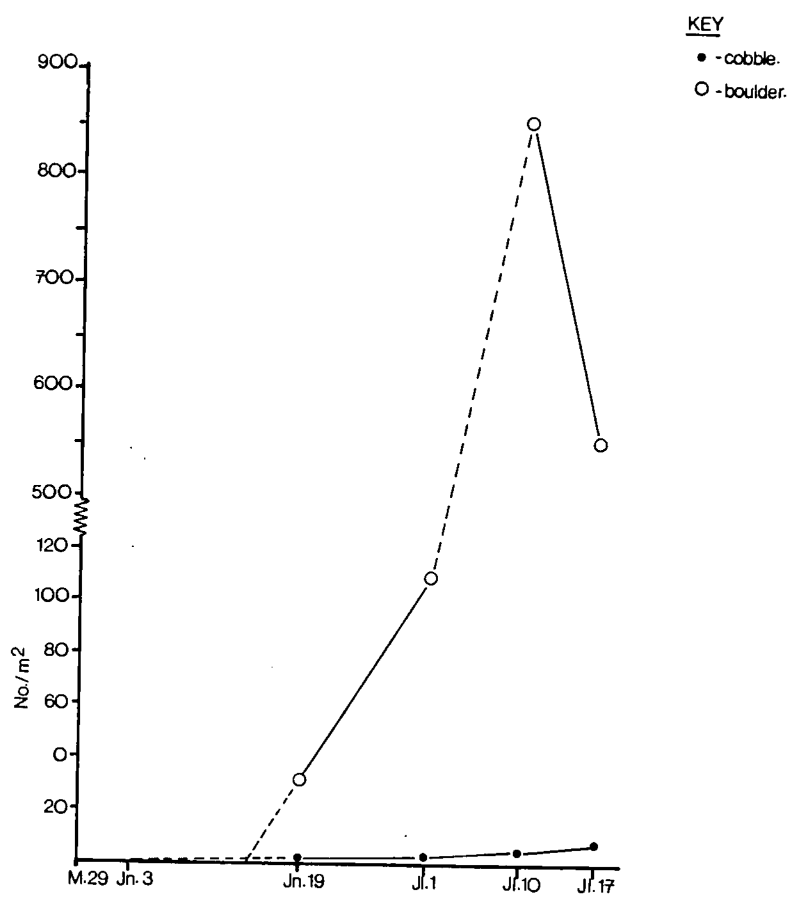




Figure 2 Comparison of numbers per $m^2$ of *Hydrobia jenkinsi* in cobble and boulder substrates through the sampling period May to July 1985.

TRICLADIA

The two species of Planarian identified in this study occurred solely at station 2 - the boulder substrate. Both species had clumped distributions, which is why their overall density appeared low. Both species need a hard surface for attachment and gliding and they are both active predators.

Dugesia ligubris feeds mainly on Gastropods, whereas Polycelis tenuis will take a range of invertebrates such as insect larvae and nymphs, Oligochaetes and Asellus, particularly when damaged but never when dead (Reynoldson, 1978). The reason for both species having a limited distribution is probably that they were unable to burrow beneath the cobble stones where most potential prey would be found in a medium or high silt concentration. They were therefore restricted to the largely silt-free boulder substrate.

HIRUDINEA

Six species of leech were found but three (see Table 1) were taken rarely and were not considered in any detail. These were Theromyzon tessulatum, an ectoparasite on waterfowl, Haementaria costata, sanguivorous on birds, amphibians and mammals, and Dina lineata, found on one occasion only. This species which has similar feeding habits to Erpobdella octoculata was first recorded in Britain in 1952 (Mann) and is thought to be spreading.

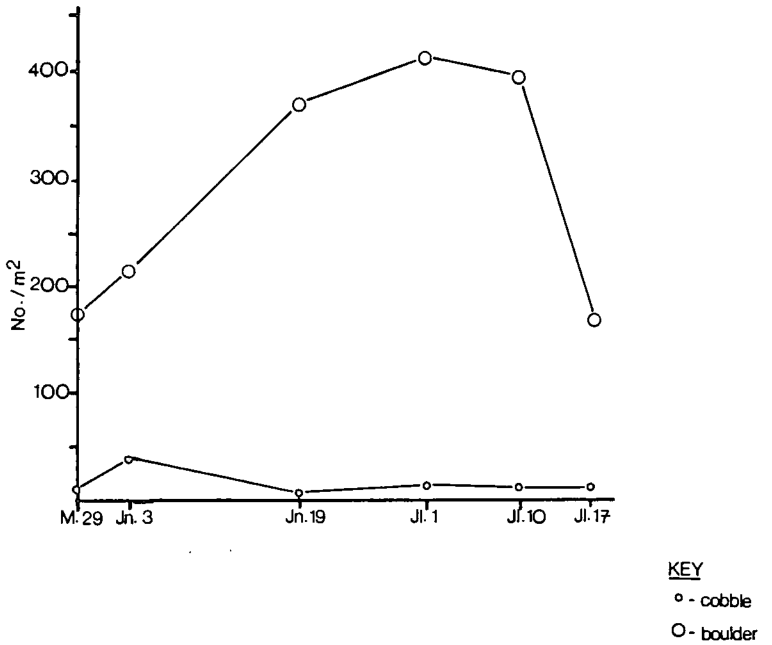
Leeches require a hard surface for movement by sucker attachment and for cocoon deposition and are usually found on stones or macrophytes. In this respect both stations 1 and 2 were suitable for leeches. Not all species have the ability to attach eggs firmly to the substratum however, and current veloicity is an important factor limiting the distribution of species. Helobdella stagnalis is often associated with macrophytes where it is usually more abundant than on stones. This species is sanguivorous on a range of invertebrates including Chironomid larvae and Ephemeropters. It also feeds on carrion. In this study Helobdella was found only on the cobble substrate, usually under stones or in dense growth of Cladophora . The eggs are laid in thin cocoons and covered by the parent. Each egg develops an attachment organ and adheres to the ventral surface of the parent. After hatching the young use their posterior sucker to attach to the parent (Elliott and Mann, 1979). It is possible that the eggs and young of Helobdella do not develop a strong enough attachment to prevent themselves from being swept downstream in the stronger current at station 2. Glossiphonia complanata also occurred sporadically but at both stations. As this species cements its eggs to the substratum and then broods them (Mann, 1955) it can be seen to possess better adaptation for life at higher current velocities than Helobdella. Glossiphonia feeds mainly on molluscs, of which there were more species and higher numbers at station 2.

Erpobdella octoculata was by far the most abundant leech at both sampling stations. This common species devours whole Chironomid larvae, Oligochaetes, Trichoptera larvae, Asellus and dead Gammarus pulex. The eggs are laid in tough cocoons cemented firmly to rocks. This vulnerable stage is therefore protected although high mortality occurs by predation. The highest mortality occurs, howevere, in the young stages where over 86% of the immatures die in their first six months (Elliott, 1973). The higher current velocities at station 2 may be responsible for keeping the population there at a lower level than at station one where leeches were found most often beneath stones. Immatures of all three species were predominating by the end of the study period, in keeping with the facts known about their life cycles.

CRUSTACEA (MALACOSTRACA)

Both species found in the survey are well known omni- and detritivores and can reach extremely high densities where suitable conditions exist. Their substrate requirements are less restricted than any of the preceding groups as they do not need to attach themselves to a hard surface. This

Figure 3 Comparison of numbers per $m^2$ of Gammarus pulex in cobble and boulder substrates through the sampling period May to July 1985.



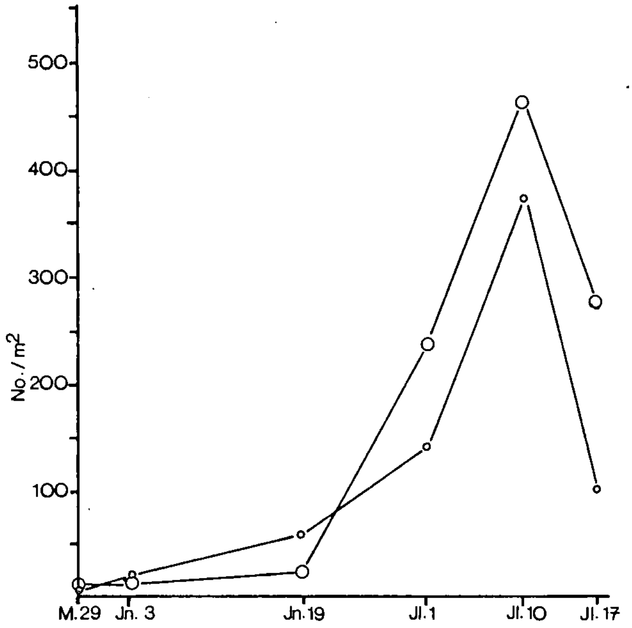




Figure 4 Comparison of numbers per $m^2$ of Baetis rhodani through the sampling period May to July 1985.

factor prevents their becoming abundant at very high current velocities as they are unable to maintain their position. In such situations suitable food is also likely to be scarce - another limiting factor.

Asellus aquaticus was found at both sampling stations throughout the study period although it was usually more abundant at station two. This species is similar in appearance to terrestrial woodlice and walks over the substrate. Asellus is common in all types of freshwater and is known to tolerate fairly high levels of pollution, often appearing in high numbers downstream from a sewage outfall. The breeding season effectively lasts from February or March until October (Steel, 1961) so little can be gained from trying to assess any differences between size classes on the two substrates in such a short study period.

Gammarus pulex is known to have a similarly extended breeding season - January to October (Macan, 1970). This species swims over the substrate unlike Asellus, and is less tolerant of polluted conditions. Gammarus was far more abundant at station two - the boulder substrate (see Table 1). The peak of the breeding season appeared to be at the beginning of July (Fig 3) when most small individuals were present. The individuals were gathered into dense groups under stones sheltered from the current. They were feeding on allochthonous material - mainly tree leaves which had become trapped in the substrate. This form of microdistribution in relation to a patchy environment is described by Gee (1979). The mobile Gammarus are well equipped to redistribute and relocate themselves when and if new food sources become available.

## PLECOPTERA AND EPHEMEROPTERA

Only one species of stonefly was found as a nymph, and this only sporadically. Isoperla grammatica is common in stony rivers and streams.

One adult specimen of another stonefly, _Brachycera risi_ was captured as it emerged. Nymphs of this species are found occasionally in moss in rivers, but otherwisein small stony streams (Hynes, 1977).

The Ephemeroptera have diversified widely, species becoming adapted to most types of clean freshwater. It is within the Ephemeroptera that some of the greatest specialisations to life in running water occur. Nymphs of the Baetidae, particularly genus _Baetis_ are almost perfectly streamlined, having the greatest diameter approximately one third of the body length from the head. The Baetidae can be described as positively rheophilic - they actively seek a current into which they face (Jaag and Ambuhl, 1964). _Baetis rhodani_ is a strong swimmer between stones and from the results it would seem to be indifferent to differences in substrate and current velocity at the two sampling stations. This species showed two peaks of abundance corresponding to the bivoltine life cycle observed by Macan (1957) - Fig 4.

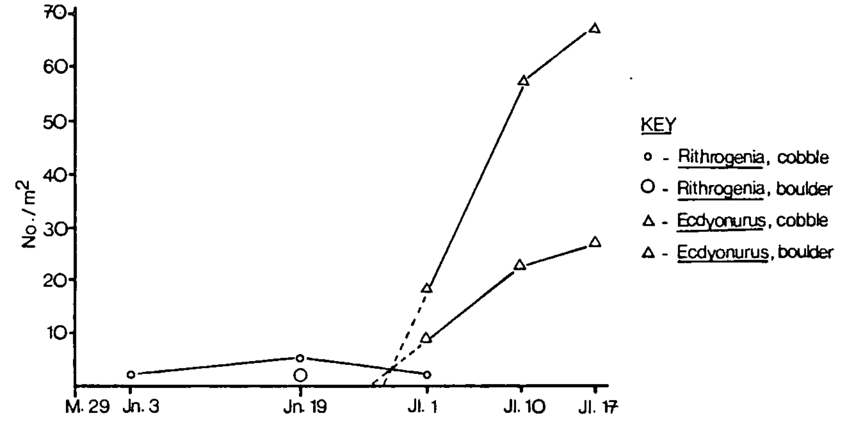
_Ecdyonurus dispar_ is another species apparently adapted for life at high current velocities. It is dorso-ventrally flattened enabling it to keep close to the substrate in the boundary layers. These are films of progressively slower moving water as the substrate is approached - ie within a few millimetres of the stone surfaces. They form when the current gradually ceases owing to friction with the substrate. Most studies assume _Ecdyonurus_ to be indifferent to variations in current velocity. There is another school of thought, however, which believes (at least in America) that the flattened form of the Ecdyonuridae is an adaptation for crawling under stones and thus avoiding the current (Dodds and Hisaw, 1924). The ability of _Ecdyonurus_ to crawl backwards and sideways would be a helpful adaptation to this mode of life and it was noted that most individuals were found under stones . If _Ecdyonurus_ does prefer to avoid currents, this would explain why the species was more abundant at station one than at station two. In the cobble substrate the quantities of silt around the stones show that the current is almost completely retarded within the substrate.

Rithrogenia semicolorata, another species of Ecdyonuridae occurred sporadically up to the beginning of July. This species is similar in appearance to Ecdyonurus and the lack of temporal overlap between the two species may be a mechanism whereby competition is reduced or avoided - see Fig 5.

Caenis macrura is known only from river sites with a substratum of gravel or smaller stones and with silt deposited (Macan, 1979). Little is known about the life cycle of this species but it is thought to have more than one generation per year in central Europe. The species does not appear to be adapted for life at high current velocities and so probably favours the underside of stones where the current is least. Caenis was absent from the boulder substrate, which ties in therefore with its known habitat distribution.

Ephemerella ignita like Caenis and Ecdyonurus appeared midway through the sampling period. This species reached very high numbers during sampling and is known as one of the most common and abundant mayflies. Ephemerella has a well-described and flexible life history (Elliott, 1978), allowing it to remain in the egg stage for over six months until conditions favourable for the growth of the nymph are realised. Numbers of Ephemerella were considerably higher at station two - the boulder substrate - than at station one. This is probably due to the ovipository behaviour of the female. Unlike the Baetidae, the adult females of which enter the water to lay their eggs beneath stones, Ephemerella detaches its egg mass at the water surface. Percival and Whitehead (1928) found that the eggs fall rapidly to the substrate and they were most abundant in moss. This leads to the supposition that the eggs become entangled in moss at station two but do not attach readilyto stoney substrates. As moss was present exclusively at station two it would seem that the difference in numbers of Ephemerella can be satisfactorily explained.

Figure 5 Comparison of numbers per $m^2$ of Rithrogenia semicolorata and Ecdyonurus dispar in cobble and boulder substrates through the sampling period May to July 1985.



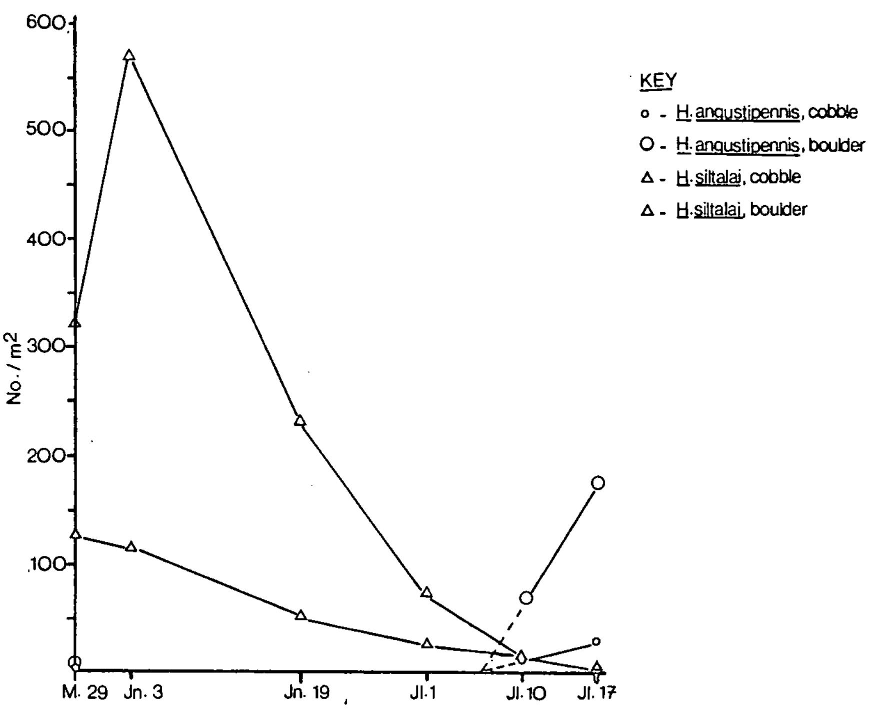




Figure 6 Comparison of numbers per $m^2$ of Hydropsyche siltalai and Hydropsyche angustipennis in cobble and boulder substrates through the sampling period May to July 1985.

TRICHOPTERA

The Trichoptera is a very diverse group, the major reason for this being the ability of the larvae to produce silk (Mackay and Wiggins, 1979). Larval Trichoptera can be divided into three functional groups based on this ability. The most primitive group - the Rhyacophilidae - of which Rhyacophila dorsalis is a member, consists of free-living larvae which are active predators. Rhyacophila was found sporadically throughout the sampling period - although there was an increase towards the latter end - mainly on the boulder substrate. Slack (1936) found that of twelve species of Trichoptera examined, only Rhyacophila was predominantly predacious. Prey included larval Hydropsyche, Simulidae and Chironomidae and also nymphs of Baetis. Scott (1958) found higher densities of Rhyacophila on coarse substrates and suggested that this may be related to feeding habits. In a given area large stones will cover a greater area of stream bottom than small stones. Such an increase of total area of sheltered microhabitat would tend to result in an increase in the density of general bottom fauna and therefore in an increased food supply for Rhyacophila. It has been suggested that Rhyacophila will also feed on the eggs of certain fish, such as Cottus gobio, but Fox (1978) found no field evidence for this.

The Hydropsychoidea are the second functional group, having adopted a sedentary strategy. The combination of larval shelters on various rock faces and different dimensions of net meshes suited to particular current speeds have led to a high level of partitioning of food resources. Members of this group found in the study were Hydropsyche angustipennis Hydropsyche siltalai and Polycentropus flavomaculatus. The latter species appeared only at the end of the sampling period. Elliott (1968) found this species to be bivoltine - having two flight periods per year. There was no evidence for this in the Wear, only small individuals being found. The two species of Hydropsyche were both abundant although at different times during the sampling period (see Fig 6). H.siltalai has a well-studied life cycle (e.g Elliott, 1968, Boon, 1979). It is usually described as univoltine, and this would appear to be the case in the Wear. The life cycle of H.angustipennis has not been described in detail but this also is thought to have one flight period. The Hydropsychidae typically construct their feeding nets in rapidly flowing water at right angles to the water current. They may also construct nets in crevices between and under stones. The stones at station two not only had a moss cover, which Boon (1979) found H.siltalai to be abundant in, but also had a less regular shape, providing safe retreats for larval Hydropsychidae. The difference in numbers of both species at the two sampling stations can probably be attributed to the lack of suitable sites for net construction at station one. It is possible that the difference in timing of the life cycles coupled with different net construction, particularly net size and mean shape,allowed the two species of Hydropsyche to co-exist, while exploiting a similar food resource.

The third functional group - the Limnephiloidea - use their silk to help manufacture cases in which they spend their larval period, enlarging the case when necessary. These cases allow the animal to be mobile and yet they provide protection, camouflage, ballast, buoyancy, streamlining and structural rigidity. There is a rich diversity in case materials and architecture suggesting resource partitioning. Several species of cased caddis were found, although not all could be identified because of inadequate keys. Those that were identified are discussed below.

Two species of Leptoceridae were found, although only one - Athripsodes bilineatus could be identified to species. Athripsodes was slightly more common at station one, on the cobble substrate. Little is known about the life cycle of this species although Hickin (1953) observed the adults swarming in late July. Agraylea multipunctata - a member of the Hydroptilidae known as "microcaddis" was found during its fifth and final larval instar only, in a small silk and Cladophora case. This group has two modes of existence and passes through a heteromorphosis during its larval period. The first four larval instars are free living,

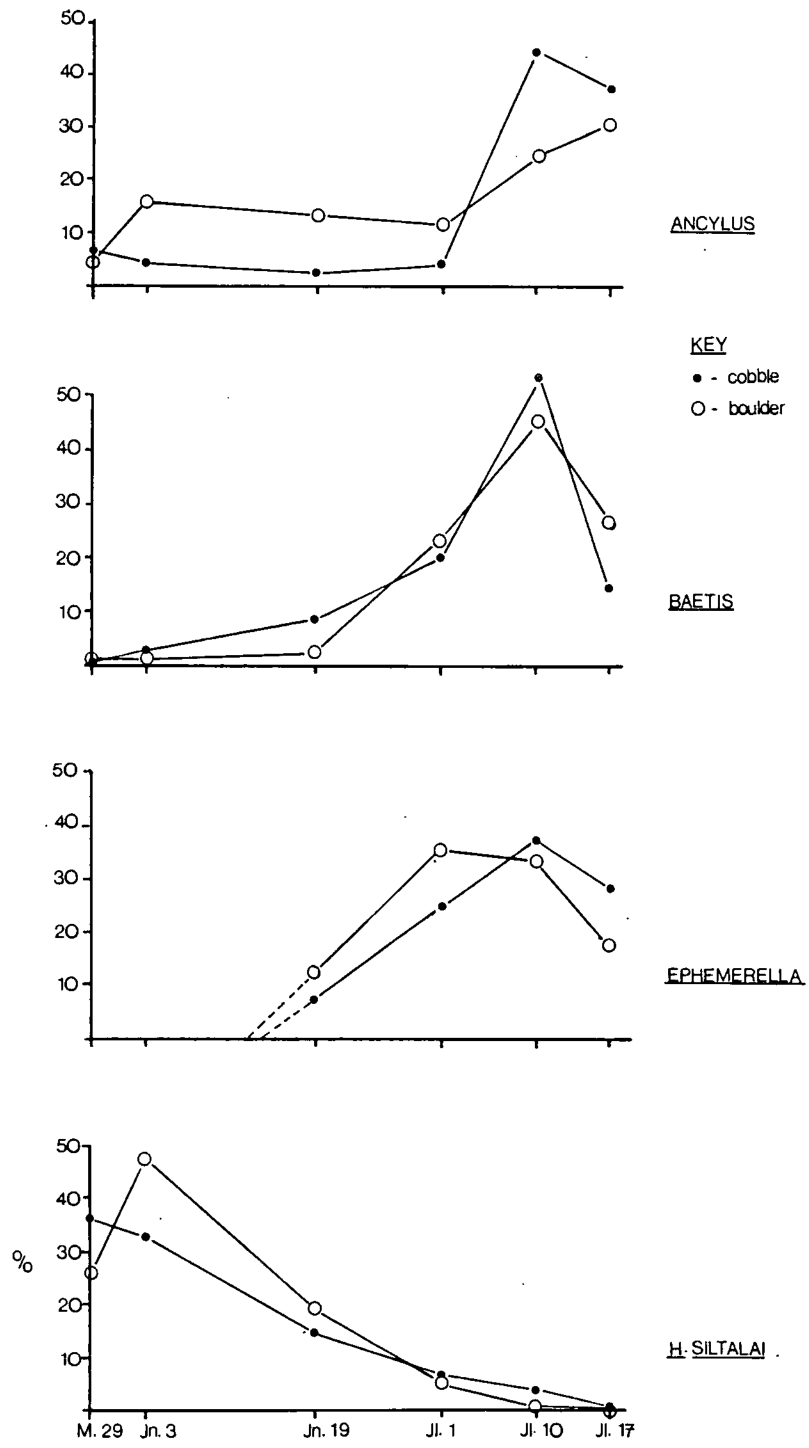



Figure 7 Comparison of abundance of four common species on cobble and boulder substrate in the River Wear, with abundance expressed as a percentage of the total occurrence of that species on each substrate.

and were not found in this study, probably because of their very small size. Agraylea feeds by piercing cells of Cladophora and sucking out the contents, this being one of the few aquatic invertebrates to feed on living aquatic multicellular plants. Numbers of Agraylea were similar at both stations although it appeared that the fifth instar occurred earlier at station one (see table 1).

COLEOPTERA

Nine species of beetle were found, many in both larval and adult forms. The family represented by the largest number of species was the Elminthidae with five species. These are known as riffle beetles, hence their occurrence on these substrates. There were few individuals found - see table 1 - method two not seeming to collect as many as method one, and so no statistical treatment was possible. Little is known about the ecology or life cycles of these small species, but they seem to be generally distributed.

DIPTERA

Of the many species of Diptera undoubtedly present in the samples, only a few could be identified to species. This was partly due to the lack of available keys but mainly because the large numbers of individuals would have necessitated a great deal of time for identification. Several species of simulidae and a few of the more distinctive species, such as Bezzia sp. and Pericoma fuliginosa could be picked out - see appendix 2. Method two did not give quantitative samples of Chironomidae and many other groups as they were small and difficult to see with the naked eye. Many Chironomidae would also have been lost by passing through the net mesh as they have very narrow bodies.

B. Quantitative results

It was thought necessary to compare the two sampling methods before any statistical analysis was performed, to ensure that they gave comparable data. Both methods were used on July 17 and from Appendeces G and H it can be seen that there are noticeable differences in the data, particularly obvious in the Tricladia, Gammarus and the Coleoptera. Because of these differences it was decided not to include the data obtained by method one in statistical tests as the magnitude of difference between the two methods may have biassed the results. Accordingly, data from May 29 to July 17 were used.

There were eight species abundant enough for statistical analysis to be performed, and these could be divided into two groups:

1) Those species with sufficient numbers for statistical tests. This group was comprised of Ancylus, Gammarus, Caenis, Ecdyonurus and Hydropsyche angustipennis.

2) Those species which could also be subdivided into size classes. This group contained Baetis, Ephemerella and Hydropsyche siltalai.

Chi-squared tests were performed on all of these species to assess whether or not numbers of individuals at the two sampling stations were significantly different. Data for the tests were taken from table one. The number of dates from which data could be used was limited in some species because of the low numbers in one or both samples. Where expected values were less than five, data from a particular date were discarded.

Table 2 Comparison of numbers per square metre of eight common species of invertebrate at two stations in the River Wear with values of chi-squared, degrees of freedom and levels of significance.

| | $\chi^2$ | df | Level of significance |
|---|---|---|---|
| Ancylus | 84.55 | 5 | P 0.001 |
| Gammarus | 75.89 | 5 | P 0.001 |
| Baetis | 74.59 | 5 | P 0.001 |
| Caenis | 6.12 | 2 | P 0.05 |
| Ecdyonurus | 0.24 | 2 | NOT SIG |
| Ephemerella | 155.69 | 3 | P 0.001 |
| H.angustipennis | 0.38 | 1 | NOT SIG |
| H.siltalai | 47.96 | 4 | P 0.001 |

From the above it can be seen that most species tested showed significant differences between the two substrates, with the exceptions of Ecdyonurus and H.angustipennis. Ecdyonurus, although it had different absolute values at each station, those at station one being approximately double those at station two, showed a similar trend at both sites. This was reflected in the result of the test and can be seen in Fig.5. The small number of samples of H.angustipennis is probably responsible for the insignificant result. It can be seen from Fig.6 that the populations at stations one and two appeared to be growing at different rates, and more samples would probably have led to a significant result.

Ancylus showed a significant difference between the substrates attricutable to the large and rapid rise in numbers towards the end of sampling at station one (see Fig.1). It appears that there was a reverse in the trends shown by this species, as at the start of sampling, numbers of Ancylus were higher at station two.

Gammarus numbers as previously described were consistently higher at station two than at station one (see Fig.3). Numbers at station two followed a near normal distribution whilst those at station one fluctuated, giving rise to a significant result.

That Baetis should show a significant difference between the substrates is perhaps surprising when Figs 4 and 7 show a high degree of similarity between the two populations. It could be that as samples were used from throughout the sampling period, small differences between populations on the two substrates were magnified by the test giving rise to the significant result.

The remaining species - Caenis, Ephemerella and H.siltalai showed the expected significant results to fit the facts known about their distribution and ecology. Caenis has only been found on fine substrates in this country and it was not therefore expected to occur in high numbers on the boulder substrate at station two. Ephemerella, as previously described, has a characteristic ovipositionary behaviour, which would lead to a higher hatching success on the boulder substrate. More nymphs would therefore be expected there. H.siltalai was also expected to be more abundant on the boulder substrate because of the greater number of physical niches for case construction.

Baetis rhodani

Table 3 Comparison of size classes of nymphs of Baetis rhodani on cobble and boulder substrates, with values of chi-squared, degrees of freedom and levels of significance.

| 1985 | COBBLE | | | BOULDER | | | $\chi^2$ | df | Level of significance |
|---|---|---|---|---|---|---|---|---|---|
| | S | M | L | S | M | L | | | |
| May 29 | 2 | 2 | 2 | 3 | 1 | 8 | - | - | - |
| June 3 | 8 | 3 | 9 | 6 | 3 | 5 | - | - | - |
| June 19 | 3 | 9 | 17 | 17 | 6 | - | 27.16 | 2 | $P \leq 0.001$ |
| July 1 | 112 | 16 | 14 | 167 | 38 | 31 | 3.04 | 2 | NOT SIG |
| July 10 | 165 | 182 | 27 | 221 | 159 | 82 | 28.54 | 2 | $P < 0.001$ |
| July 17 | 27 | 41 | 31 | 40 | 140 | 95 | 8.23 | 2 | $P < 0.05$ |

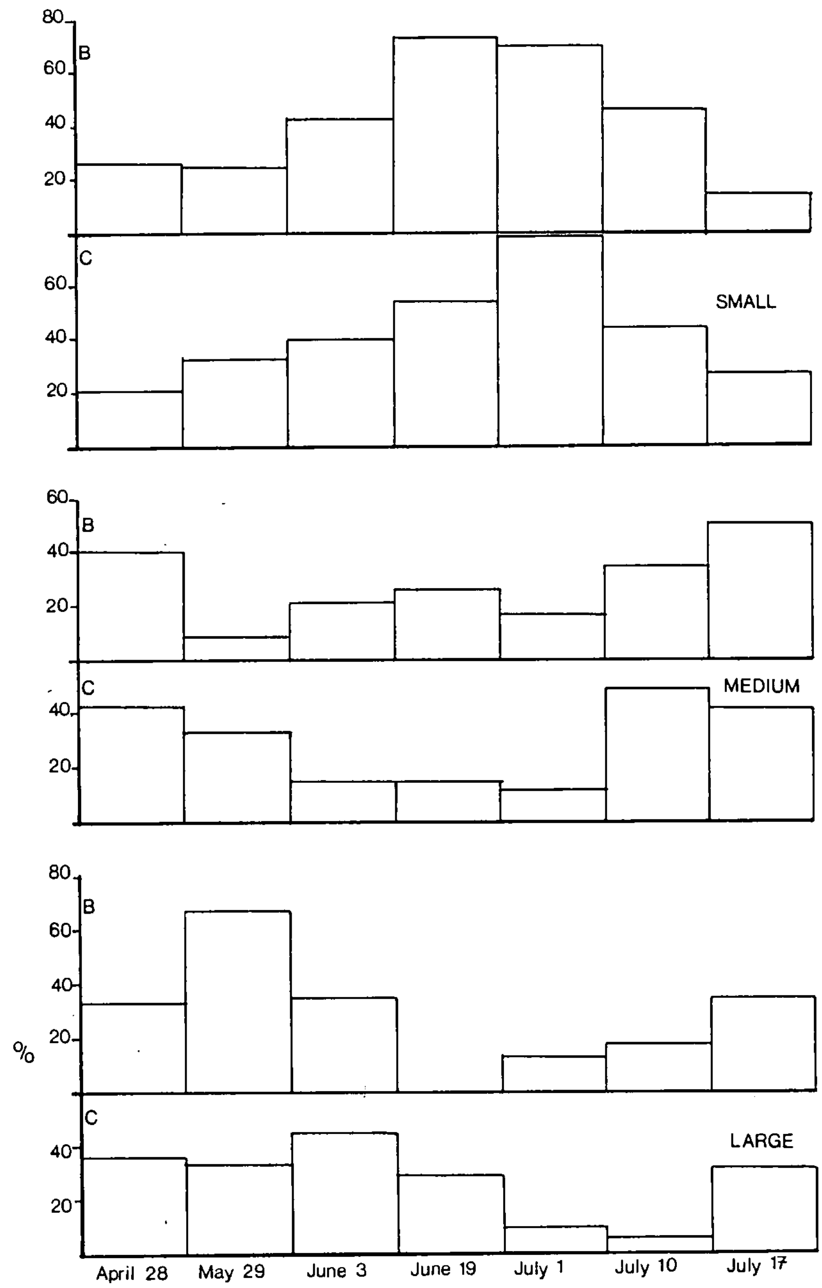



Figure 8  Comparison of the size classes of nymphs of *Baetis rhodani* on (B) boulder and (C) cobble substrates in the River Wear through the sampling period, with abundance expressed as a percentage of the total caught on each substrate at each sampling date.

Table 3 would seem, like the results from the previous section, to indicate differences between the samples taken from the two substrates which are not discerned in a qualitative review. Fig.8 shows the size class data for Baetis converted into percentages, and from this it can be seen that the date on which any particular size class was dominant varied between the two substrates. For example, small nymphs predominated on July 1 at station one but had peaked by June 19 at Station two. The medium and large size classes show similar differences - earlier peak percentages on boulder substrates.

Table 4 shows that although the first generation of Baetis appears to end later at station one, the second generation is more synchronous and develops more rapidly than on the boulder substrate. At station two there seemed to be a protracted start to the second generation, small nymphs predominating on three successive sampling dates.

Table 4 The dominant size class of nymphs of Baetis rhodani on each sampling date (1985).

| | COBBLE | BOULDER |
|---|---|---|
| May 29 | - | L |
| June 3 | L | L |
| June 19 | L | S |
| July 1 | S | S |
| July 10 | M | S |
| July 17 | M | M |

Ephemerella ignita

Table 5 Comparison of size classes of nymphs of Ephemerella ignita on cobble and boulder substrates with values of chi-squared, degrees of freedom and levels of significance.

| 1985 | COBBLE | | | BOULDER | | | $\chi^2$ | df | Level of significance |
|---|---|---|---|---|---|---|---|---|---|
| | S | M | L | S | M | L | | | |
| June 19 | 157 | 24 | - | 257 | 78 | 63 | 40.04 | 2 | $P \leq 0.001$ |
| July 1 | 351 | 142 | 83 | 235 | 606 | 279 | 270.22 | 2 | $P \leq 0.001$ |
| July 10 | 230 | 480 | 160 | 182 | 296 | 560 | 258.66 | 2 | $P \leq 0.001$ |
| July 17 | 152 | 221 | 286 | 81 | 160 | 367 | 92.07 | 2 | $P \leq 0.001$ |

S= small nymphs $<$ 5mm

M= medium nymphs 5-10mm

L= large nymphs $>$ 10mm

Table 5 shows significant differences in size distribution to have existed between the stations on all dates. Fig 9 shows very clearly the differences in time between peaks of the various size classes at the two stations. This is particularly obvious in medium sized nymphs, where the boulder substrate group peaks on July 1 whereas the cobble substrate group does not predominate until July 10. Table 6 also shows this - development occurring later on the cobble substrate. The reasons for this cannot be ascertained from the present data, but could be linked with the ovipository behaviour of the adult female as previously discussed on page 23.

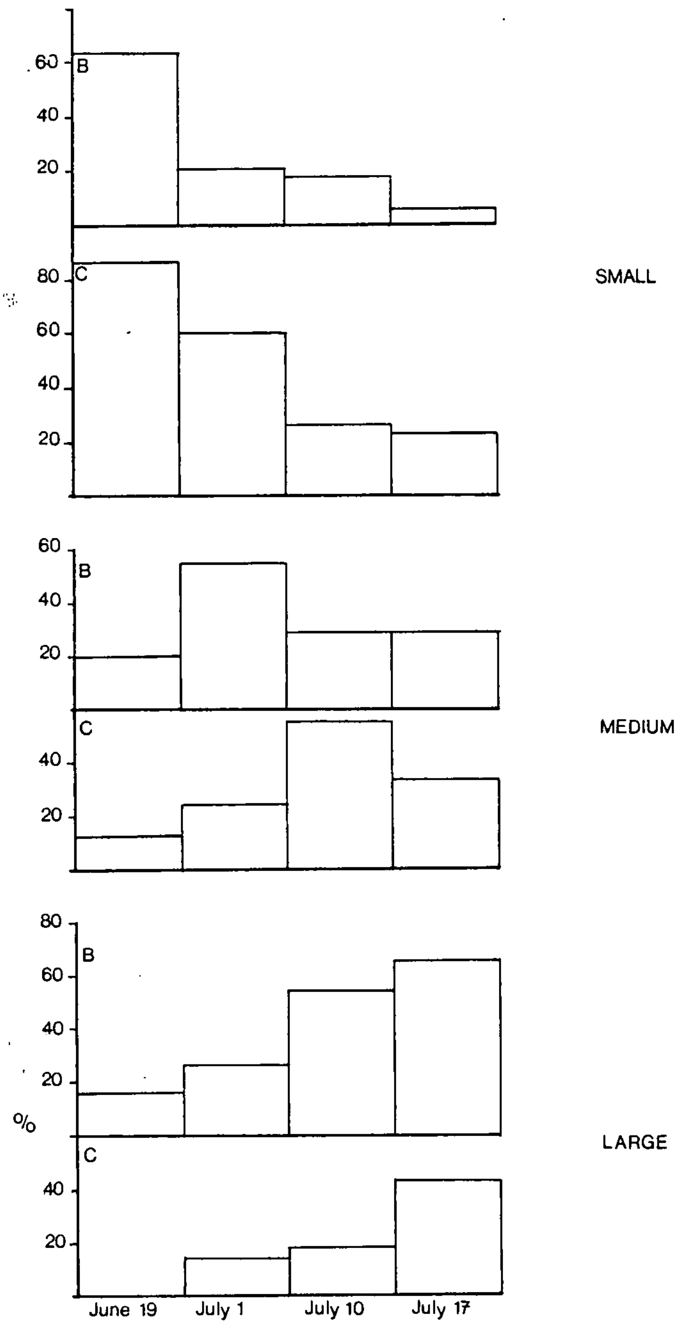



Figure 9 Comparison of the size classes of nymphs of *Ephemerella ignita* on (B) boulder and (C) cobble substrates in the River Wear through the sampling period, with abundance expressed as a percentage of the total caught on each substrate at each sampling date.

Table 6 The dominant size classes of *Ephemerella ignita* on each sampling date (1985).

| | COBBLE | BOULDER |
|---|---|---|
| June 19 | S | S |
| July 1 | S | M |
| July 10 | M | L |
| July 17 | L | L |

*Hydropsyche siltalai*

Table 7 Comparison of larvae of *Hydropsyche siltalai* on cobble and boulder substrates with values of chi-squared, degrees of freedom and level of significance.

| 1985 | COBBLE | | | BOULDER | | | $\chi^2$ | df | Level of significance |
|---|---|---|---|---|---|---|---|---|---|
| | S | M | L | S | M | L | | | |
| May 29 | 30 | 73 | 25 | 124 | 164 | 30 | 14.54 | 2 | $P \leq 0.001$ |
| June 3 | 13 | 58 | 96 | 79 | 386 | 104 | 25.20 | 2 | $P \leq 0.001$ |
| June 19 | 6 | 31 | 16 | 52 | 103 | 75 | 4.45 | 2 | NOT SIG |
| July 1 | 1 | 11 | 11 | 7 | 15 | 50 | 6.50 | 2 | $P \leq 0.05$ |
| July 10 | - | 9 | 8 | 1 | 2 | 8 | - | - | - |
| July 17 | - | - | 2 | - | - | 2 | - | - | - |

S= small larvae < 8mm

M= Medium larvae 8-16mm

L= large larvae >16mm

Table 7 shows there to have been significant differences between the cobble and boulder substrate groups of *H.siltalai* through most of the study period. At the latter end, there were insufficient numbers of larvae for statistical tests to be performed as most individuals had

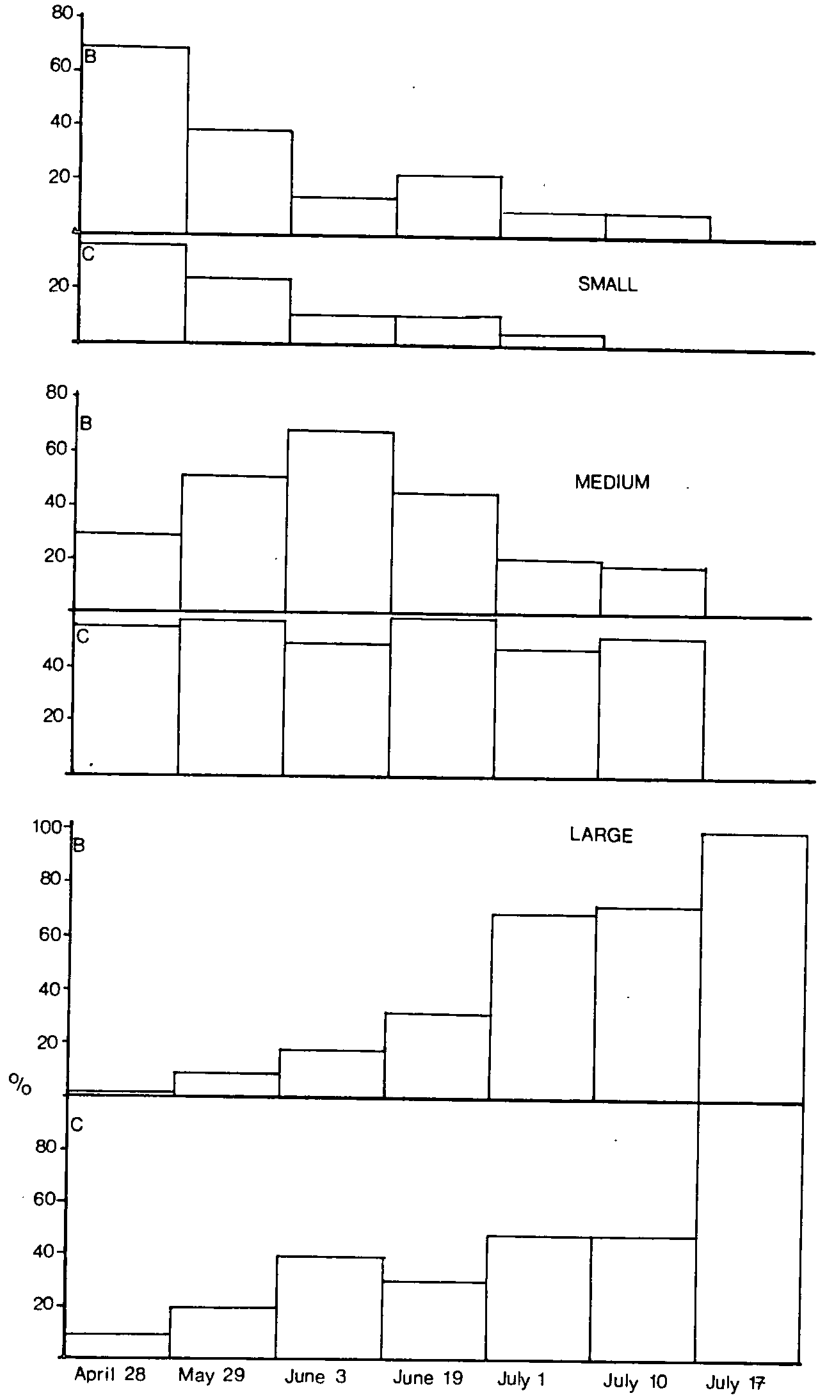



Figure 10 Comparison of size classes of larvae of Hydropsyche siltalai on (B) boulder and (C) cobble substrates in the River Wear the sampling period, with abunoance expressed as a percentage of the total caught on each substrate at each sampling date.

pupated. It would seem from Fig.10 that the differences between the stations were not great, with the exception of the medium size class which on the cobble substrate maintained a similar proportion of the population until the last sampling date, whereas on the boulder substrate there was a definite peak on June 3.

A considerable amount of further investigation would be required to establish the reasons for the differences in size class distribution between the two substrates. Even though the reasons are not clear, it is interesting, however, to note the existance of such differences.

## 6. DISCUSSION

As seen from the results, variability in the substrate affects the invertebrate fauna. Some species are profoundly affected, others less so, but the overall result in this survey was to give the two areas chosen for study totally different characters although they appear to be rather similar superficially.

Scott (1954) states that "The quantitative distribution of the (Trichoptera) larvae among the different microhabitats of the stream bed follows the quantitative distribution of the food supply on the stream bed". This probably applies to groups other than the Trichoptera and it can be deduced that the food supply is related to the type of substrate to be found in an area. In this study, at station 1, Cladophora and epilithic algae were abundant and fine particulate organic matter was deposited around the stones. At station 2, there was moss (Fontinalis sp.) as well as Cladophora , and this was present throughout the year, adding a new dimension to the habitat. Moss may not have grown at station 1 because of silt being deposited on it and smothering it, whereas at station 2 the current speed and craggy nature of the substrate prevented this. Although fine particulate organic matter could not accumulate at station 2, it's precursor, coarse particulate organic matter was present in the form of leaves and woody material trapped between the boulders.

The nature of the food supply at station 1 supported a community based on algal grazers, such as Ancylus, and the functional feeding group of 'collectors' (Cummins and King, 1979) - some mayflies and net-spinning caddisflies - for example. At station 2, the fauna was dominated by 'shredders' such as Gammarus and cased caddis larvae, the former being particularly abundant. Algal grazers and 'collectors' were also present. Associated with each type of community were predators - the flat worms, leeches and the free-living caddis larva

Rhyacophila. These have an obvious relationship with their food supply, the distribution of leeches, for example is primarily affected by food availability (Sawyer, 1974).

Although food supply is probably the most important factor affecting the presence and abundance of species, there are other variables of great importance and these too are connected with the nature of the substrate. Firstly, the nature of the surface of the substrate has vital consequences for invertebrates. A smooth worn surface has fewer suitable sites for invertebrates to find shelter in than a rough and irregular surface. The number of narrow crevices was limited at station 1, whereas at station 2 they were abundant, almost every stone having a highly irregular surface. Many species prefer to be associated with cracks and crevices as these provide safe retreats from potential predators. The Hydropsychidae are typical examples of this type of invertebrate and are vulnerable because they build ther nets on the upper surfaces of stones where they are particularly obvious to predators. Nymphs of Baetis, which also tend to be found on the upper surfaces of stones rapidly search for shelter if alarmed (Percival and Whitehead, 1929) and would be more likely to find suitable shelter at station 2.

Secondly the growth of moss at station 2 will have had a definite effect on some species. Ephemerella is one species known to have an affinity for macrophytes. Percival and Whitehead (1929) found the highest densities of this species to occur in loose clumps of moss, such as were found at station 2, rather than in extremely dense growths. Ecdyonurus, conversely, has a wide body unsuited to movement through thick matted vegetation and was found generally on bare stones, which were more abundant at station 1. Thirdly, the presence of boulders emerging above the water surface at station 2 would be important for the oviposition of some insects, such as Baetis, adult females of which crawl into the water to lay their eggs on the undersurfaces of stones (Percival and

Whitehead, 1928). The emergence of certain species of Ephemeroptera and Trichoptera is also dependant on stones or vegetation above the water surface on which they can expand their wings and dry-off. The availability of suitable sites for oviposition probably had greater significance here, as adults emerging from one riffle are quite likely to migrate the short distance to the other riffle, unless there is a strong wind against them, whereas it would be virtually impossible for nymphs or larvae to make that same journey.

From the above it can be seen that station 2 provided a more diverse habitat than station 1, judging by the number of available physical and ecological niches. The higher number of species and individuals of many species seems to prove this. Therefore Hynes' statement that the larger the stones, the more diverse the invertebrate fauna can be seen to apply, even at the large end of the substrate particle size gradient. It must, however, be realised that the absolute size of stones is not the only relevant factor, although it may be the major one. This study has shown that there is a different type of community in each riffle based on the avalable food resources which may vary as a result of substrate particle (stone) size. The more coarse the substrate, the larger the average size of pieces of organic material trapped, and therefore available as food for invertebrates. Coarse substrates allow a community based on shredders of large pieces of organic material to develop. Thus, in the boulder substrate, collectors of fine particulate organic matter feed on the products of shredders rather than on material deposited by the current. The number of emerging stones is also related directly to particle size, but the number of physical niches and the growth of moss are only indirectly linked. These latter factors are more closely related to current velocity, as it is the current that determines how much silt is deposited and how greatly the stones are ground together, causing them to lose the irregularities favoured by invertebrates.

Current speed and substrate particle size can be said to be the most important environmental factors affecting aquatic invertebrates. From the results of this study, substrate particle size appears to be the dominant parameter, as it directly affects the food supply available to invertebrates. Current velocity, however, shapes the environment in which they live, thus effecting long-term changes in the fauna as the character of the substrate is altered.

Appendix 1 (A) Raw data of samples taken April 28th 1985 - method 1

| | COBBLE | | | | | | | | | | BOULDER | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| MOLLUSCA | | | | | | | | | | | | | | | | | | | | |
| A. fluviatilis | | 1 | 1 | 10 | 3 | 1 | 1 | | | | 7 | 10 | 5 | 1 | 1 | 5 | 5 | 2 | | 10 |
| H. jenkinsi | 2 | 1 | 1 | | | 1 | 1 | | 1 | 3 | 3 | 1 | 4 | | 1 | 1 | 4 | | 1 | 2 |
| L. peregra | | | | | | | | | | | 3 | | 1 | | 1 | | | | | |
| Pisidium sp. | 5 | 1 | 1 | | 1 | | 6 | | | | 18 | 4 | 38 | 2 | 5 | 3 | 4 | | 2 | 17 |
| HIRUDINEA | | | | | | | | | | | | | | | | | | | | |
| E. octoculata | 2 | 5 | 6 | 1 | 4 | 3 | 5 | | | 1 | | 2 | 1 | 2 | 1 | 1 | | 1 | 2 | |
| G. complanata | | | | | | | | | | | | | | | 1 | | | | | |
| H. stagnalis | | 1 | | | | | | | | | 1 | | | | | | | | | |
| CRUSTACEA | | | | | | | | | | | | | | | | | | | | |
| A. aquaticus | 9 | | | | 2 | 2 | | | | | 1 | | 6 | | 3 | 1 | 3 | | 1 | 2 |
| G. pulex | 152 | | 1 | 3 | 4 | 5 | 11 | 2 | 2 | 3 | 623 | 543 | 1195 | 2 | 510 | 382 | 101 | 28 | 33 | 340 |
| INSECTA | | | | | | | | | | | | | | | | | | | | |
| Plecoptera | | | | | | | | | | | | | | | | | | | | |
| I. grammatica | 3 | | | | | | | | | | | | 1 | 1 | | | | 1 | | |
| Ephemeroptera | | | | | | | | | | | | | | | | | | | | |
| B. rhodani | 48 | 12 | 23 | 19 | 33 | 53 | 7 | 18 | 16 | 15 | 51 | 23 | 56 | 6 | 19 | 13 | 102 | 46 | 18 | 18 |
| R. semicolorata | | | | | | 1 | | | | | | | 1 | 1 | | | | | | |
| Trichoptera | | | | | | | | | | | | | | | | | | | | |
| H. angustipennis (1) | 2 | 1 | 1 | 1 | | 1 | | | | 1 | 5 | 5 | 1 | | | 3 | 6 | 4 | 2 | |
| H. siltalai (1) | 16 | 1 | 3 | 11 | 5 | 1 | 5 | 1 | 2 | 3 | 14 | 59 | 53 | | 15 | 23 | 78 | 15 | 9 | 17 |
| R. dorsalis (1) | | 1 | | | 1 | | | | | | | | | 1 | | | | | | |
| Coleoptera | | | | | | | | | | | | | | | | | | | | |
| B. elevatus | | | | | | | | | | | 1 | | | | | | | | | |
| E. aenea | | | 1 | | | | | | | | | | 2 | | | 1 | 2 | | | |
| L. volckmari (a) | | | 1 | | 1 | | | 1 | 1 | | 1 | 2 | 2 | | 1 | 1 | 1 | | | |
| L. volckmari (1) | | 8 | 11 | 11 | 3 | 1 | | 4 | 1 | 1 | 1 | | 4 | 2 | 1 | 8 | 15 | 1 | 1 | |
| S. canaliculata (A) | | 1 | 7 | | | | 2 | | | | | 6 | | 4 | 4 | | | | | |

(1) - larvae
(a) - adults

Appendix 1 (B) Raw data of samples taken May 29th 1985 - method 2

| | COBBLE | | | | | | BOULDER | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 |
| MOLLUSCA | | | | | | | | | | | | |
| A. fluviatilis | 2 | 3 | 8 | | 2 | 2 | 1 | | | 2 | 4 | |
| Pisidium sp. | | | | | 1 | | 2 | | | | | |
| TRICLADIA | | | | | | | | | | | | |
| D. ligubris | | | | | | | 2 | | | | | |
| P. tenuis | | | | | | | | 1 | | | | 1 |
| HIRUDINEA | | | | | | | | | | | | |
| E. octoculata | | 3 | 6 | 4 | 2 | 9 | | | | | | |
| G. complanata | | | | | 2 | | | | | | | |
| CRUSTACEA | | | | | | | | | | | | |
| A. aquaticus | | 2 | | | 2 | | 7 | | | | | |
| G. pulex | 1 | 1 | | 3 | 1 | | 15 | 26 | 17 | 4 | 11 | 45 |
| INSECTA | | | | | | | | | | | | |
| Ephemeroptera | | | | | | | | | | | | |
| B. rhodani | 1 | | | 1 | 2 | | 1 | 4 | | 2 | 1 | |
| Trichoptera | | | | | | | | | | | | |
| H. angustipennis (l) | | | | | | 1 | | 1 | | | 2 | |
| H. angustipennis (p) | | | | | | | | | 3 | | | |
| H. siltalai (l) | 12 | 38 | 11 | | 12 | 12 | 41 | 4 | 66 | 39 | 29 | 33 |
| Leptoceridae sp. | 7 | 6 | 16 | 11 | 6 | 34 | 2 | 4 | 2 | 11 | 5 | 13 |
| R. dorsalis (l) | | | | | | | | | | 1 | | |
| R. dorsalis (p) | | 7 | | | | | | | | 1 | | |
| Coleoptera | | | | | | | | | | | | |
| H. elegans (a) | 1 | | | | | | 1 | | | | | |

(l) - larvae
(p) - pupae
(a) - adults

Appendix 1 (C) Raw data of samples taken June 3rd 1985 - method 2

| | COBBLE | | | | | | BOULDER | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 |
| MOLLUSCA | | | | | | | | | | | | |
| A. fluviatilis | 3 | 1 | 1 | 3 | 1 | 2 | 2 | 4 | 1 | 7 | 7 | 7 |
| Pisidium sp. | | | | | | | | | 2 | 1 | | |
| TRICLADIA | | | | | | | | | | | | |
| D. ligubris | | | | | | | | | | 1 | | 1 |
| P. tenuis | | | | | | | | | 1 | | 1 | 1 |
| HIRUDINEA | | | | | | | | | | | | |
| D. lineata | | | | 1 | | | | | | | | |
| E. octoculata | 2 | | | 4 | 6 | | | 1 | | | 3 | |
| H. stagnalis | | | | 1 | | | | | | | | |
| CRUSTACEA | | | | | | | | | | | | |
| A. aquaticus | | | | 1 | 1 | | | | | | | |
| G. pulex | 6 | 5 | 11 | 2 | | 1 | 33 | 19 | 27 | 31 | 14 | 18 |
| INSECTA | | | | | | | | | | | | |
| Plecoptera | | | | | | | | | | | | |
| I. grammatica | | | | | | | | | | | | 2 |
| Ephemeroptera | | | | | | | | | | | | |
| B. rhodani | 3 | 1 | 2 | 4 | 1 | 2 | | 2 | 1 | 2 | 4 | |
| R. semicolorata | | | | | | 1 | | | | | | |
| Trichoptera | | | | | | | | | | | | |
| H. angustipennis (p) | | | 2 | | 1 | | | | | | | |
| H. siltalai (l) | 27 | 2 | 14 | 24 | 1 | 10 | 44 | 74 | 6 | 109 | 47 | 45 |
| H. siltalai (p) | | | 5 | 3 | 2 | | 2 | 4 | 3 | 8 | 5 | 3 |
| Leptoceridae sp. | 12 | 3 | 7 | 51 | 5 | 3 | 1 | 16 | 28 | 20 | 42 | 24 |
| R. dorsalis (l) | | | | 1 | | | | | | | | |
| R. dorsalis (p) | | | | 1 | | | | 3 | 3 | 7 | 4 | 1 |
| Coleoptera | | | | | | | | | | | | |
| H. elegans | | | 1 | 1 | | | | | | | | |
| L. volckmari (l) | | | | | | 1 | 2 | | | 1 | 1 | 1 |
| L. volckmari (a) | | | | | 1 | | | | | | | |

(l) - larvae
(p) - pupae
(a) - adults

Appendix 1 (D) Raw data of samples taken June 19th 1985 - method 2

| | COBBLE | | | | | | BOULDER | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 |
| MOLLUSCA | | | | | | | | | | | | |
| A. fluviatilis | 2 | 2 | 6 | 2 | | 2 | 5 | 6 | 1 | 2 | 4 | 3 |
| H. jenkinsi | | | | | 1 | | 4 | 4 | 5 | 5 | 1 | 2 |
| Pisidium sp. | | | | | | | | | | | 2 | |
| TRICLADIA | | | | | | | | | | | | |
| D. ligubris | | | | | | | | | | | 20 | |
| P. tenuis | | | | | | | | | | | 13 | |
| HIRUDINEA | | | | | | | | | | | | |
| E. octoculata | 2 | 3 | 4 | 1 | 1 | 5 | | 2 | | | 1 | |
| G. complanata | | | 1 | | | | | | | | 1 | |
| H. stagnalis | | 2 | | | 1 | | | | | | | |
| CRUSTACEA | | | | | | | | | | | | |
| A. aquaticus | | | | | | | 4 | | | | | 2 |
| G. pulex | | | | | 2 | | 46 | 46 | 44 | 28 | 69 | 22 |
| INSECTA | | | | | | | | | | | | |
| Ephemeroptera | | | | | | | | | | | | |
| B. rhodani | 9 | 9 | 5 | 8 | 1 | 6 | | 6 | 4 | 1 | 2 | 2 |
| C. macrura | | 5 | 5 | 31 | 5 | 10 | 4 | 1 | | | 1 | |
| E. ignita | 10 | 31 | 15 | 27 | 19 | 18 | 61 | 34 | 30 | 26 | 65 | 49 |
| R. semicolorata | | 1 | 1 | | | 1 | | | | | 1 | |
| TRICHOPTERA | | | | | | | | | | | | |
| A. bilineatus | | | 1 | | | 1 | 1 | | 1 | 1 | | 1 |
| H. siltalai (l) | 1 | 21 | 5 | 3 | 3 | 2 | 13 | 21 | 48 | 27 | 22 | 22 |
| H. siltalai (p) | | | 2 | | 3 | 1 | 2 | 1 | 17 | 6 | 8 | 9 |
| Leptoceridae sp. | 2 | 1 | 22 | 10 | 12 | 2 | 14 | 17 | 10 | 6 | 18 | 8 |
| R. dorsalis (l) | | 1 | | | | | 1 | | | | | |

(l) - larvae
(p) - pupae

Appendix 1 (E) Raw data of samples taken July 1st 1985 - method 2

| | COBBLE | | | | | BOULDER | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| MOLLUSCA | | | | | | | | | | |
| A. fluviatilis | 2 | 4 | 2 | 1 | 1 | 1 | 4 | 2 | 6 | 3 |
| H. jenkinsi | | | | | 1 | | 13 | 6 | 4 | 30 |
| Pisidium sp. | | | | | | | 1 | | | 1 |
| TRICLADIA | | | | | | | | | | |
| D. ligubris | | | | | | | 1 | | | 1 |
| P. tenuis | | | | | | 1 | | | | |
| HIRUDINEA | | | | | | | | | | |
| E. octoculata | | 1 | 1 | 2 | 2 | 1 | | | | 5 |
| T. tessulatum | | | | | | 1 | | | | |
| CRUSTACEA | | | | | | | | | | |
| A. aquaticus | 3 | | 1 | | | 7 | 1 | | 1 | 3 |
| G. pulex | | 4 | | 2 | 1 | 18 | 87 | 9 | 37 | 77 |
| INSECTA | | | | | | | | | | |
| Plecoptera | | | | | | | | | | |
| I. grammatica | | | 1 | | | | | | | |
| Ephemeroptera | | | | | | | | | | |
| B. rhodani | 23 | 10 | 14 | 14 | 18 | 15 | 32 | 51 | 14 | 19 |
| C. macrura | 4 | 4 | 2 | 2 | 15 | | | | | 3 |
| E. dispar | 3 | 4 | | 3 | | | 1 | 2 | | 2 |
| E. ignita | 118 | 38 | 57 | 24 | 83 | 102 | 148 | 201 | 59 | 111 |
| R. semicolorata | | 1 | | | | | | | | |
| Trichoptera | | | | | | | | | | |
| A. multipunctata | 2 | 1 | 2 | 3 | 2 | 1 | 1 | | | |
| A. bilineatus | | | 3 | | | 1 | 1 | | 2 | 1 |
| H. siltalai (l) | | 1 | 6 | 3 | 3 | | 9 | 10 | 14 | 7 |
| H. siltalai (p) | 1 | 5 | 2 | 3 | 1 | | 2 | 6 | 14 | 8 |
| Leptoceridae sp. | 29 | 3 | 16 | 21 | 19 | 14 | 15 | 17 | 12 | 33 |
| R. dorsalis (l) | | | | 1 | | | | | | |
| R. dorsalis (p) | | | 1 | | | | | | | |
| Coleoptera | | | | | | | | | | |
| L. volckmari (l) | | | 1 | | | | | | | 1 |
| L. volckmari (a) | | | 1 | | | | | | | |
| E. parallelepipedus | | 1 | | | | | | | | |

(l) - larvae
(p) - pupae
(a) - adults

Appendix 1 (F) Raw data of samples taken July 10th 1985 - method 2

| | COBBLE | | | | | | BOULDER | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 |
| MOLLUSCA | | | | | | | | | | | | |
| A. fluviatilis | 14 | 17 | 12 | 19 | 23 | 24 | 1 | 1 | 2 | 10 | 7 | 19 |
| H. jenkinsi | | | | 1 | | 2 | 23 | 64 | 12 | 353 | 131 | 84 |
| L. peregra | | | | | | | | | | 2 | 3 | 5 |
| Pisidium sp. | | | | | | | | | 2 | 1 | 2 | 5 |
| TRICLADIA | | | | | | | | | | | | |
| D. ligubris | | | | | | | 2 | | | | 2 | |
| P. tenuis | | | | | | | 1 | | | | | |
| HIRUDINEA | | | | | | | | | | | | |
| E. octoculata | 1 | | 1 | | 1 | | 1 | 2 | | 2 | 1 | |
| H. costata | | | 1 | | | | | | | | | |
| T. tessulatum | | | | | | | 1 | | | | | |
| CRUSTACEA | | | | | | | | | | | | |
| A. aquaticus | | 1 | | 1 | 1 | | 1 | 2 | 1 | 5 | 2 | 2 |
| G. pulex | 1 | | 1 | 4 | 2 | 1 | 30 | 47 | 32 | 66 | 33 | 54 |
| INSECTA | | | | | | | | | | | | |
| Ephemeroptera | | | | | | | | | | | | |
| B. rhodani | 47 | 71 | 11 | 55 | 14 | 51 | 36 | 93 | 83 | 42 | 39 | 15 |
| C. macrura | 4 | 5 | 4 | 2 | 2 | 7 | 1 | | | 2 | 1 | 3 |
| E. dispar | 3 | 6 | 5 | 9 | 5 | 10 | 5 | 2 | | 2 | 3 | 3 |
| E. ignita | 126 | 139 | 56 | 96 | 53 | 110 | 92 | 204 | 84 | 148 | 86 | 78 |
| Trichoptera | | | | | | | | | | | | |
| A. multipunctata | 4 | 1 | | 4 | 3 | 4 | 1 | 5 | 5 | 1 | 4 | 2 |
| A. bilineatus | 1 | | | | | | | 1 | 1 | 1 | | |
| H. angustipennis (l) | 1 | 2 | 2 | 4 | 1 | | 5 | 5 | 9 | 7 | 8 | 12 |
| H. siltalai (l) | 2 | 7 | 1 | 1 | | | 2 | 1 | 2 | 1 | | 1 |
| H. siltalai (p) | 7 | 11 | 2 | 6 | | 2 | 4 | 1 | 8 | 6 | 7 | 13 |
| Leptoceridae sp. | 2 | | 2 | | 1 | | 1 | 1 | 2 | 1 | | |
| R. dorsalis (l) | | | | | | | 1 | 1 | | | | 1 |
| R. dorsalis (p) | | 1 | | | | | | | | | | |
| Coleoptera | | | | | | | | | | | | |
| E. aenea (l) | | | | | 1 | | | | | | | |
| E. parallelepipedus (l) | | | | 1 | | | | | | | | |
| H. elegans | | | | | | | | | | 1 | | |
| L. volckmari (l) | | | | | 1 | | | | | | | |
| L. volckmari (a) | | | | | | | | | | 1 | | |

(l) - larvae
(p) - pupae
(a) - adults

Apendix 1 (G) Raw data of samples taken July 17th 1985 - method 2

| | COBBLE | | | | | BOULDER | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| MOLLUSCA | | | | | | | | | | |
| A. fluviatilis | 7 | 7 | 29 | 22 | 13 | 9 | 4 | 14 | 7 | 6 |
| H. jenkinsi | 1 | | 1 | 2 | | 140 | 32 | 34 | 43 | 59 |
| L. peregra | | | | | | 1 | | 2 | 1 | |
| Pisidium sp. | | | | | | | 1 | | | |
| TRICLADIA | | | | | | | | | | |
| D. ligubris | | | | | | 1 | 1 | 2 | 1 | 1 |
| P. tenuis | | | | | | | 1 | 16 | 2 | 1 |
| HIRUDINEA | | | | | | | | | | |
| E. octoculata | | 3 | 2 | 6 | 2 | 1 | | | | |
| G. complanata | | | 2 | | | | | | | 1 |
| H. stagnalis | | | | | 1 | | | | | |
| CRUSTACEA | | | | | | | | | | |
| A. aquaticus | | 2 | | 1 | 5 | 7 | 2 | 7 | 3 | 2 |
| G. pulex | 1 | 1 | 1 | 1 | 2 | 12 | 32 | 15 | 15 | 19 |
| INSECTA | | | | | | | | | | |
| Plecoptera | | | | | | | | | | |
| I. grammatica | | 1 | | | | | | | | |
| Ephemeroptera | | | | | | | | | | |
| B. rhodani | 13 | 5 | 13 | 9 | 15 | 30 | 27 | 18 | 27 | 51 |
| C. macrura | | 11 | 1 | | 5 | | | | | |
| E. dispar | 2 | 4 | 12 | 13 | 6 | 1 | 2 | 5 | 4 | 3 |
| E. ignita | 72 | 62 | 112 | 64 | 56 | 57 | 88 | 38 | 56 | 51 |
| Trichoptera | | | | | | | | | | |
| A. multipunctata | 1 | | | 1 | 2 | 2 | 2 | 3 | 2 | 1 |
| H. angustipennis (l) | 2 | 1 | 1 | 3 | 9 | 21 | 19 | 16 | 23 | 19 |
| H. siltalai (l) | 1 | | | | | | | | | 1 |
| H. siltalai (p) | 1 | 1 | 1 | 3 | 4 | 1 | 8 | 3 | 2 | |
| Leptoceridae sp. | | | | | | | | 1 | | |
| P. flavomaculatus (l) | 1 | 1 | | | | | | | | |
| R. dorsalis | | | | | | | | | | 8 |
| Coleoptera | | | | | | | | | | |
| E. aenea (l) | | | | 1 | | | | | 1 | 1 |
| L. volckmari (l) | | 1 | | | | | | | | |
| O. tuberculatus (l) | | | | | | 1 | | | | |

(l) - larvae
(p) - pupae

Appendix 1 (H) Raw data of samples taken July 17th 1985 - method 1

| | COBBLE | | | | | BOULDER | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| MOLLUSCA | | | | | | | | | | |
| A. fluviatilis | 5 | 9 | 20 | 9 | 7 | 2 | 3 | 5 | 5 | 6 |
| H. jenkinsi | 2 | 8 | 7 | 2 | 5 | 117 | 61 | 214 | 157 | 103 |
| L. peregra | | | | | | 1 | | 2 | 5 | 3 |
| Pisidium sp. | | 10 | 8 | | 15 | 4 | | 2 | 12 | 4 |
| TRICLADIA | | | | | | | | | | |
| D. ligubris | | | | | | | 2 | 2 | 1 | 2 |
| HIRUDINEA | | | | | | | | | | |
| E. octoculata | | | 3 | | 2 | | | 1 | 1 | |
| G. complanata | | | | | 1 | 1 | | | | |
| H. stagnalis | | | 1 | | | | | | | |
| CRUSTACEA | | | | | | | | | | |
| A. aquaticus | | 5 | | | 4 | 10 | | 3 | 9 | 2 |
| G. pulex | 5 | 24 | 28 | 4 | 20 | 205 | 527 | 362 | 434 | 487 |
| INSECTA | | | | | | | | | | |
| Plecoptera | | | | | | | | | | |
| I. grammatica | 4 | 3 | | 1 | 1 | | | | 2 | 1 |
| Ephemeroptera | | | | | | | | | | |
| B. rhodani | 56 | 46 | 65 | 42 | 46 | 22 | 67 | 71 | 45 | 58 |
| C. macrura | 4 | 43 | 25 | | 21 | 3 | 2 | 3 | 3 | 2 |
| E. dispar | 13 | 11 | 13 | 10 | 15 | 2 | 3 | 4 | 4 | 3 |
| E. ignita | 92 | 85 | 129 | 49 | 112 | 30 | 58 | 67 | 55 | 52 |
| Trichoptera | | | | | | | | | | |
| A. multipunctata | | | 1 | | | 1 | | | | 1 |
| A. bilineatus | | | 3 | | | | | | | |
| H. angustipennis (l) | 11 | 6 | 5 | 1 | 6 | 7 | 26 | 9 | 9 | 11 |
| H. siltalai (p) | 1 | | 4 | | | | 2 | | 1 | 1 |
| P. flavomaculatus (l) | | 2 | | 1 | | 1 | 2 | | | 2 |
| R. dorsalis (l) | | | | | | | | 2 | | |
| Coleoptera | | | | | | | | | | |
| E. parallelepipedus (l) | 1 | 9 | 7 | 3 | 7 | 2 | 1 | | 1 | 1 |
| E. parallelepipedus (a) | 1 | 3 | | 2 | | | | | | |
| H. elegans (a) | | | | | | | 1 | | | |
| Hydroporus sp. (l) | | | | | | | | | 1 | |
| L. volckmari (l) | 2 | | 1 | 7 | 2 | | 4 | 3 | 1 | 1 |
| L. volckmari (a) | 5 | | | | 2 | | | | | |
| O. tuberculatus (l) | | 6 | 6 | 2 | 2 | | 1 | | 1 | |
| O. tuberculatus (a) | | | | | 1 | | | | | |
| S. canaliculatus | 10 | 25 | 9 | 6 | 7 | | | | 1 | |

(l) - larvae
(p) - pupae
(a) - adults

Appendix 2 (A). Species list of all invertebrates identified from the River Wear, Durham April to July 1985.

| | |
|---|---|
| MOLLUSCA | |
| Ancylus fluviatilis | (Macan A) |
| Hydrobia jenkinsi | (Macan A) |
| Lymnaea peregra | (Macan A) |
| Pisidiium sp. | (Macan B) |
| | |
| TRICLADIA | |
| Dugesia ligubris | (Reynoldson) |
| Polycelis tenuis | (Reynoldson) |
| | |
| HIRUDINEA | |
| Dina lineata | (Elliott & Mann) |
| Erpobdella octoculata | (Elliott & Mann) |
| Glossiphonia complanata | (Elliott & Mann) |
| Haementaria costata | (Elliott & Mann) |
| Helobdella stagnalis | (Elliott & Mann) |
| Theromyzon tessulatum | (Elliott & Mann) |
| | |
| CRUSTACEA | |
| Asellus aquaticus | (Gledhill et al) |
| Gammarus pulex | (Gledhill et al) |
| | |
| PLECOPTERA | |
| Brachycera risi | (Hynes) |
| Isoperla grammatica | (Hynes) |
| | |
| EPHEMEROPTERA | |
| Baetis rhodani | (Macan C) |
| Caenis macrura | (Macan C) |
| Ecdyonurus dispar | (Macan C) |
| Ephemerella ignita | (Macan C) |
| Rithrogenia semicolorata | (Macan C) |
| | |
| TRICHOPTERA | |
| Agraylea multipunctata | (Hickin) |
| Athripsodes bilineatus | (Wallace) |
| Leptoceridae sp. | (Wallace) |
| Hydropsyche angustipennis | (Edington & Hildrew) |
| Hydropsyche siltalai | (Edington & Hildrew) |
| Polycentropus flavomaculatus | (Edington & Hildrew) |
| Rhyacophila dorsalis | (Edington & HIldrew) |
| | |
| COLEOPERA | |
| Elmis aenea | (Holland) |
| Esolus parallelepipedus | (Holland) |
| Limnius volckmari | (Holland) |
| Oulimnius tuberculatus | (Holland) |
| Stenelmis canaliculata | (Holland) |
| Brychius elevatus | (Joy) |
| Haliplus confinis | (Joy) |
| Hydradephaga elegans | (Joy) |
| Hydroporus sp. | (Joy) |

DIPTERA

| | |
|---|---|
| Atherix sp. | (Macan B) |
| Limnophora sp. | (Macan B) |
| Bezzia sp. | (Kettle & Lawson) |
| Pericoma fuliginosa | (Satchell) |
| Simulium equinum | (Davies) |
| S. brevicaule | (Davies) |
| S. reptans | (Davies) |

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